Armed Services Technical Information Agency

Because of our limited supply, you are requested to return this copy WHEN IT HAS SERVED YOUR PURPOSE so that it may be made available to other requesters. Your cooperation will be appreciated.

AD 29849

Reproduced by

DOCUMENT SERVICE CENTER

KNOTT BUILDING, DAYTON, 2, OHIO

UNCLASSIFIED

RESEARCH MEMORANDUM

APPLICATION OF PULSE TECHNIQUES TO STRAIN GAGES

By Newell D. Sanders and George H. Brodie

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
May 4, 1954

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

APPLICATION OF PULSE TECHNIQUES TO STRAIN GAGES

By Newell D. Sanders and George H. Brodie

SUMMARY

Pulse techniques have been applied to strain gages for increasing the output level and extending the usable range. Bonded and unbonded strain gages which normally operate with exciting potentials between 3.5 and 14 volts were operated satisfactorily with 200-volt pulses of 1-microsecond duration and a repetition rate of 350 per second. Outputs 15 times greater than normal outputs were measured. A pulse-generating circuit and a pulse-detecting circuit are described. An analysis of pulsed operation of strain gages is given.

INTRODUCTION

Strain gages are convenient and commonly used measuring devices for producing electrical signals which are functions of displacements. The convenience and simplicity of such gages is offset to some extent, however, by the extremely low level of output signal. This low level of output may, in some applications, impose extreme requirements regarding stability and noise level of amplifiers associated with the gage. Through the application of pulse techniques, it may be possible to obtain outputs of tenths of volts instead of the microvolts or millivolts usually obtained. Considerable improvement in signal-to-noise ratio may result, thereby permitting extension of the lower practical limit on the range of loads which can be measured.

Reports of applications of pulse techniques to strain gages have been received from various laboratories; however, no analysis or quantitative report of results has been obtained.

This paper presents an analysis and results of an experimental investigation of the application of pulse techniques to strain gage measurements. The experimental phase included investigation of the response of bonded and unbonded strain gages to high-voltage pulses of various energy levels, investigation of problems connected with pulse power supply and transmission lines, and investigation of problems connected with strain-gage output detection.

ANALYSIS

A representative strain gage bridge will produce a maximum output at full-scale deflection of approximately 3 millivolts per volt applied to the bridge. The output can be increased, therefore, by applying an increased potential to the bridge. The applied potential is limited, however, by the heating effects of the bridge current. A high-voltage pulse of short duration may be used provided that the energy of the pulse and the heat-storage capacity of the gage are such that excessive temperature rise will not be obtained. In the pulse technique, the maximum voltage will usually be limited by the insulation breakdown value. The maximum pulse duration will be limited by heating effects. Minimum practical pulse duration is established by transmission problems and unwanted coupling between strain gage input and output circuits. 3255

The pulse technique will be illustrated by a theoretical example through application to an unbonded strain gage with the following characteristics:

Active arms	4
Over-all resistance, ohms	90
Input potential, volts	7.2
Temperature rise, °F	50
Wire size, in.	0.001
Wire material	Advance

Additional information needed in calculations:

Wire resistance per unit length, ohms/cm	9.42
Wire weight per unit length, g/cm	45.2×10^{-6}
Specific heat of wire material, cal/gram °C	0.10

A pulse repetition rate of 350 cycles per second is chosen because of requirements of a special application for the pulsed strain gage.

The gage will be subject to high-voltage pulses of short duration and of sufficient energy to bring the wire temperature to 50° F above ambient. A cooling period will then be allowed to permit cooling of the wire before another voltage pulse is applied. Typical temperature cycles are shown in figure 1. The average power over a complete cycle is approximately equal to the power dissipated in normal operation with direct current excitation.

The first step in the estimation of the temperature cycle is the estimation of the cooling rate. The cooling rate is equal to the steady-state heating rate, which may be calculated from the current and resistance of the gage wire. The total bridge current is 80 milliamperes and the current through each arm of the bridge is 40 milliamperes. The dissipation per centimeter of wire is found from the current and wire resistance of 9.42 ohms per centimeter as follows:

$$9.42\times(0.040)^2 = 0.0151 \text{ watts/cm}$$

When the current is turned off, heat continues to flow away from the wire at this rate until the temperature difference falls appreciably below 50° F. The heat is supplied by the heat capacity of the wire. This heat capacity is

Specific heat		density		heat capacity
0.10	×	45.2×10^{-6}	=	4.52×10^{-6} cal/cm °C
			=	19.3×10^{-6} joules/cm °C

The rate of temperature decrease is equal, therefore, to the quotient of heat dissipation rate and heat capacity

$$\text{Rate of temperature decrease} = 0.0151/19.3\times10^{-6}$$

$$= 0.78^{\circ} \text{ C per millisecond}$$

$$= 1.4^{\circ} \text{ F per millisecond}$$

The slope of the cooling line in figure 1 is selected to be 1.4° F per millisecond. The repetition period corresponding to 350 cycles per second is 2.86 milliseconds. The total cooling in the period is 4° F. The heating pulse must, therefore, supply sufficient energy to heat the wire 4° F.

The selection of heating pulse is simplified by first estimating the temperature rise caused by a 1-ampere pulse in the wire for 1 microsecond.

$$\text{Temperature rise} = \frac{\text{Resistance} \times \text{current}^2 \times \text{time}}{\text{Wire mass} \times \text{specific heat} \times 4.186}$$

$$= \frac{9.42 \times 1 \times 10^{-6}}{45.2 \times 10^{-6} \times 0.1 \times 4.186}$$

$$= 0.498^{\circ} \text{ C/(amp}^2\text{)(microsecond)}$$

$$= 0.9^{\circ} \text{ F/(amp}^2\text{)(microsecond)}$$

The selected temperature rise is 4° F; therefore at 1 microsecond

$$I = \sqrt{4/0.9} = 2.1 \text{ amperes}$$

I is the peak current in amperes through one arm of bridge. The required voltage across a 90-ohm bridge is 380. The voltage required for other pulse durations is shown in figure 2.

If the gage will withstand 330 volts, the maximum effective pulse duration is 1.3 microseconds and the maximum bridge output is (at 3 mv/volt) 1.0 volt.

At first glance, it might appear that a pulse of such small duration as 1.3 microseconds would be difficult to transmit because of stray capacitances in the gage, cable, and associated equipment. However, the pulse is derived from a condenser (0.04 microfarad) which is large compared to stray capacitances. An unbonded gage with 12 inches of shielded lead was found to have a stray capacitance of 85 micromicrofarads. This small capacitance will reduce the pulse amplitude only six parts in 10,000. Bonded strain gages may have stray capacitance three times this value. If the characteristic impedance of the cable equals the gage impedance, the attenuation is only of the order of 0.2 decibel per 100 feet.

3255

EXPERIMENTAL INVESTIGATION

In the initial experiments it was decided to use power supplies and detection circuits which operate at 350 cycles per second and are capable of producing pulse voltages up to 400 peak with effective pulse duration of about 1 microsecond.

The selected pulse repetition frequency will permit faithful recording from input signals with frequencies up to at least 35 cycles per second.

The effective pulse duration is defined as the duration of a rectangular pulse whose peak amplitude and energy equal those of the actual pulse.

Equipment

Strain gages. - Unbonded strain gages are frequently used in accelerometers and in pressure-measuring devices. Two commercial pressure-measuring gages of this type were selected for part of the investigation. One bonded strain gage was also used in the program. All four arms of the bridge were cemented to a steel cantilever beam. Approximate characteristics of the three units were as follows:

Gage	A	B	C
Maximum pressure, lb/in.^{2}	5	10	---
Maximum load, lb	--	---	200
Bridge resistance, ohms	90	350	350
Recommended bridge potential, volts	4.5	14	12
Maximum output, mv/volt	3	3	3

Pulse supply. - A schematic diagram of the pulse supply is given in figure 3. The pulse is formed by the discharge of the 0.04-microfarad condenser through a triggered thyratron. The bridge was coupled to the cathode circuit of the tube through a 1:1 pulse transformer. The transformer obviates grounding one of the input terminals of the bridge. The pulse-forming condenser was charged from a direct-current power supply through a 22,000-ohm resistor. The trigger pulse was supplied from a blocking oscillator driven by a convenient alternating-current source of adjustable frequency. The thyratron used was a 3D22.

The circuit diagram shows two secondary windings on the pulse transformer. In the investigation reported herein, one secondary was connected to the gage under test, and the other secondary was connected to a 51-ohm dummy load.

A split-stator air condenser was connected across the transformer secondary terminals to provide means for balancing the capacitative coupling to ground. This adjustment permits a closer approach to a null balance with the bridge than could be obtained otherwise. A potentiometer was also connected across the same terminals for improvement of the null balance point.

Pulse detector circuit. - The pulse detector circuit (fig. 4) consists of a voltage amplifier, a diode peak detector, and a pulse stretcher which is capable of holding the peak value of the pulse with negligible loss for the period of 1 cycle. Near the end of each cycle, a "dunking" circuit discharges the pulse-holding circuit in preparation for the succeeding cycle.

Typical wave forms are shown in figure 5. It can be seen that the output is essentially a direct-current signal with zero signal reference level shown in each cycle. In most of the work described in this report, the output was fed to a pen-motor type of recorder. Because of the low cut-off frequency of the pen-motor, the return-to-zero pulses did not show in the records.

The relation of input to output of the amplifier portion is shown in figure 6. The amplification factor corresponding to the slope of the line is 7500.

RESULTS

Maximum allowable voltages - The 90-ohm unbonded gage was subjected to a series of tests in which applied pulse potentials were progressively increased while effective pulse duration was maintained fixed at 1 microsecond. A typical pulse trace is shown in figure 7. At pulse potentials between 120 and 300 volts, the gage operated with no sign of deterioriation for continuous periods of 8 hours. Although precise measurements of gage sensitivity were not made, visual observations of oscilloscope traces did not show change in the relation of gage input to output. The zero setting of the gage was likewise unchanged.

The tests were terminated when the dummy load on the transformer was inadvertently disconnected, which allowed the pulse voltage to rise to values approaching 400 volts peak and the pulse duration to increase. Several hours of operation under these conditions resulted in a permanent shift of the balance point of the gage. The shift in balance point was approximately 15 percent of the full output of the gage. Visual inspection of the gage elements failed to reveal obvious damage, and except for the unusually large zero shift, the gage appeared to retain normal sensitivity. The damage may have been the result of over-heating rather than flash-over or insulation break-down.

Effective pulse duration. - Most of the investigation was conducted with pulse amplitudes and durations shown in figure 7(a). Maximum voltage was approximately 190. Figure 7(b) shows how the effective pulse duration was estimated. The ordinate is the instantaneous power (E^2/R) for the wave shown in figure 7(a). The duration of the rectangular pulse was chosen such that its area equals the area under the curve for the actual pulse. The effective duration was approximately 1 microsecond. The energy of a single pulse was approximately 540 microwatt-seconds. At a repetition rate of 350 per second, the average power was close to 0.2 watt, a value well within the rating of the gage.

Sensitivity. - The sensitivity of a strain-gage bridge when excited with short-duration pulses is expected to be lower than the sensitivity when excited with direct current because of the shunting effects of the internal capacitances within the gage. The cantilever beam with bonded strain gage was found to have a direct-current sensitivity of 3.04 millivolts output per volt of excitation potential with full load applied to the beam. When pulses having 190-volt amplitude and 1-microsecond effective duration were applied, the sensitivity dropped to 2.4 millivolts output per volt of peak excitation potential with full load applied to the beam. This loss of sensitivity is not considered to be serious provided adequate calibration procedures are followed.

The sensitivity of unbonded strain gages was not checked, but because these gages have lower capacity to ground than do the bonded gages, the sensitivity when excited with short pulses is expected to be close to the direct-current sensitivity.

When the amplitude of exciting pulses was 210 volts, the output signal at full load was 0.48 volts. This output is 15 times greater than the output usually obtained with direct-current excitation.

Minimum readable signal. - The readability with small signals was investigated by loading the cantilever beam and strain gage with 1/2 percent of rated load. The output signal was recorded on a commercial pen-motor type of recorder. The record is shown in figure 8. The gain of the amplifier was adjusted to produce approximately 0.8 of full-scale deflection with this load. The recorded trace is clear and free from noise. The record can be read to approximately 1/50 of the deflection produced by the 1/2 percent load. It is concluded that the readability is 1/100 percent of full scale. Although the electronic circuits are believed to be capable of further extension of the readability, such extension is probably not warranted because of limitations imposed by hysteresis and drift in the gage itself.

Effects of cable capacitance and inductance. - The gages used in the tests were connected to the pulse source with 60-foot cables in order to simulate conditions under which such a strain-gage system might actually be used. The power input line consisted of two 70-ohm coaxial cables used as a balanced transmission line. The output from the gage was fed to the detector through a single coaxial cable of similar type. Changing the length of the power cable requires a slight readjustment of the balance circuits associated with the pulser output transformer. The two 60-foot cables between the power supply and the gage introduced a 5-percent loss of pulse amplitude.

A bonded strain-gage bridge was substituted for the unbonded type. The significant change in the amount and distribution of the stray capacities to ground made necessary the addition of a capacity bridge across the strain-gage bridge terminals in order to obtain a good null balance. Once set, mica trimmer condensers used for the bridge balancing needed no further adjustment. A conventional-type direct-current balance control was added at the same time and the whole system enclosed in a small metal box for shielding and rigidity.

Sensitivity to external noise. - The system was found to be relatively immune to electrical disturbances. However, at high gains (1/2 percent of load for full output deflection) a coded electrical paging system in the building produced signals which were picked up by the amplifier and recorded. An example of such a record is shown in figure 9. This noise did not affect the readability materially.

Linearity. - The linearity of the complete recording system is shown in figure 10. The bonded strain gage and cantilever beam were used in this calibration. Earlier calibrations showed nonlinearity close to the balance point of the bridge, as might be expected. Linearity in figure 10 was obtained by electrically off-setting the balance point an amount equivalent to 1/4 percent of the full load of the beam and off-setting the recording pen a like amount in the opposite direction to give zero deflection at zero load.

3255

GENERAL DISCUSSION

The experiments just described do not establish the limits on the pulse technique of strain-gage measurements. The maximum allowable pulse voltages have not been determined. Neither has the maximum pulse duration as determined by gage heating been found. It is believed that the amplifier gain could be increased considerably before noise would make further increase unprofitable.

The pulse repetition frequency of 350 cycles per second was chosen with a particular application of the equipment in mind. However, it has been found that the equipment will work at repetition frequencies from 60 to 700 cycles per second.

The pulse technique is especially advantageous with low-resistance (90 ohms) bridges because the output signals contain more power than in the case of high-resistance bridges, and transmission over coaxial cables having matching impedance is convenient.

Experience with strain gages leads to the suggestion that pulse techniques might be applied to variable reluctance and differential transformer types of transducers.

CONCLUSIONS

The analysis and experiments reported herein show that high-voltage pulses in the order of 200 volts may be applied to low-voltage (10 volts) strain gages provided the duration and repetition rate of the pulses are limited to avoid overheating of the gages. Output signals are approximately 15 times greater than those ordinarily obtained. The short pulses (1 microsecond) do not introduce difficult problems in transmission, amplification, and detection.

The particular pulsed strain-gage system described herein provided readability to 1/100 of 1 percent of full scale without observable noise.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, February 9, 1954

3255

CS-2

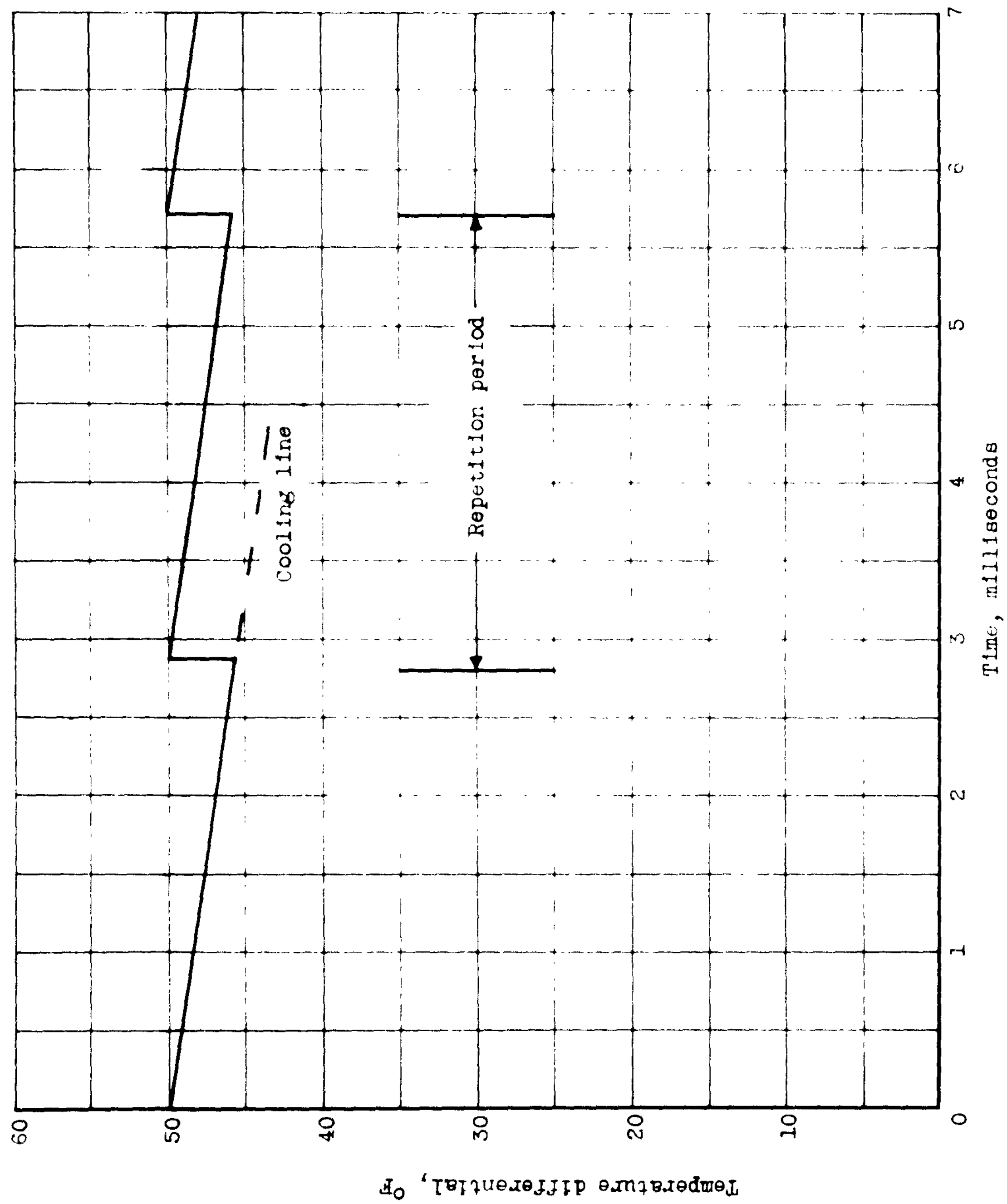


Figure 1. - Strain-gage temperature cycle.

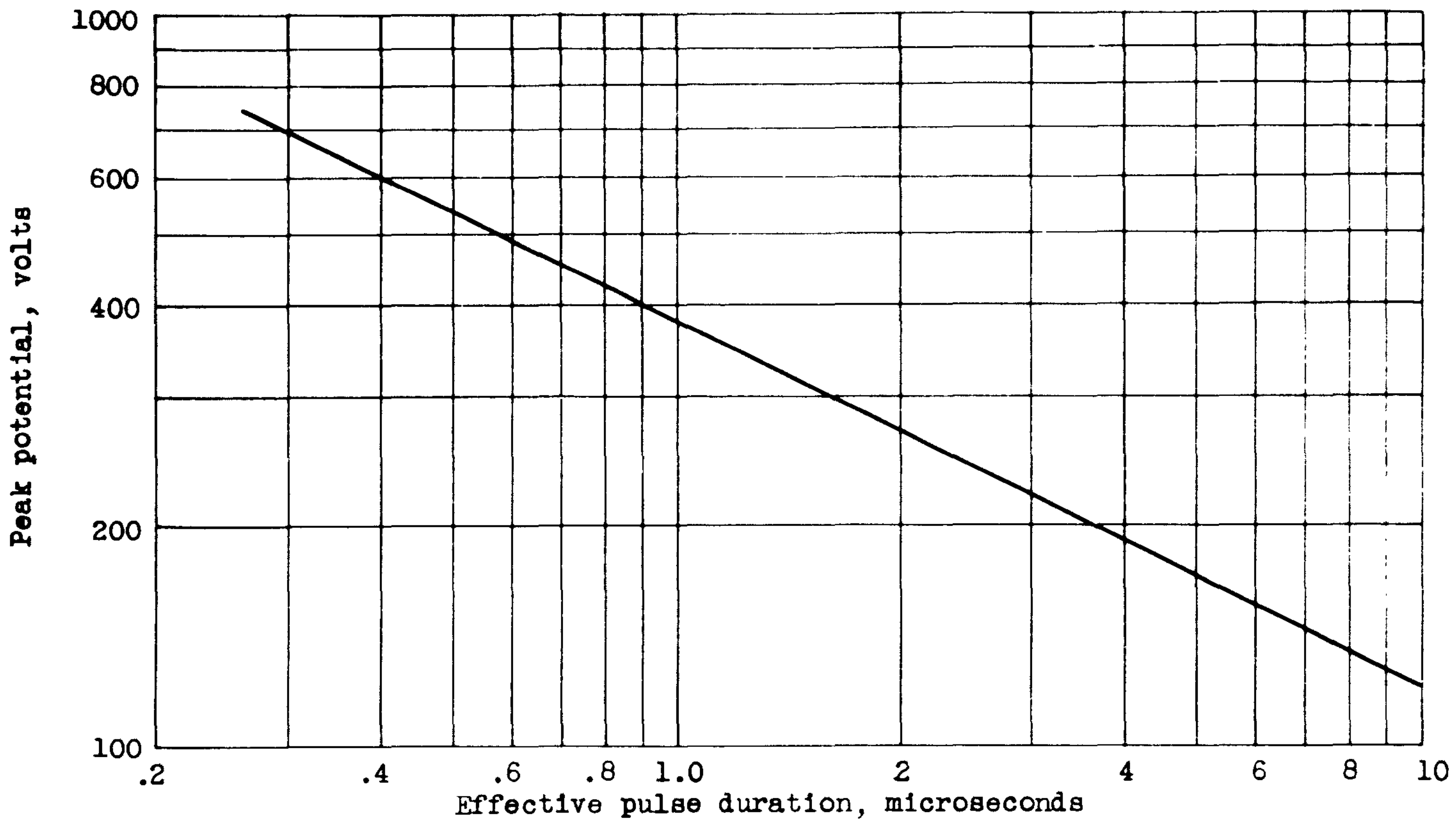


Figure 2. - Relation of allowable pulse duration to pulse height. Bridge resistance, 90 ohms; frequency, 350 cycles per second.

3255

CS-2 back

3255

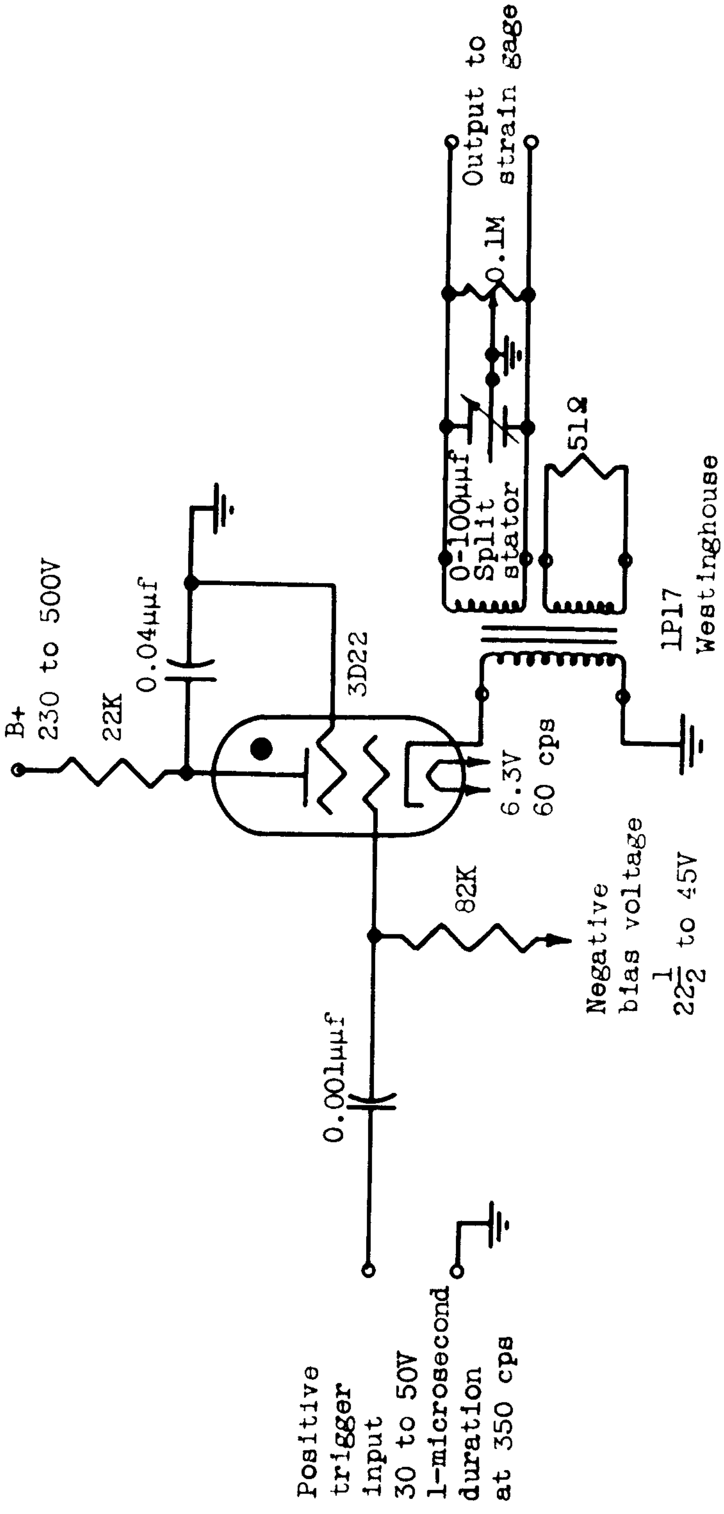
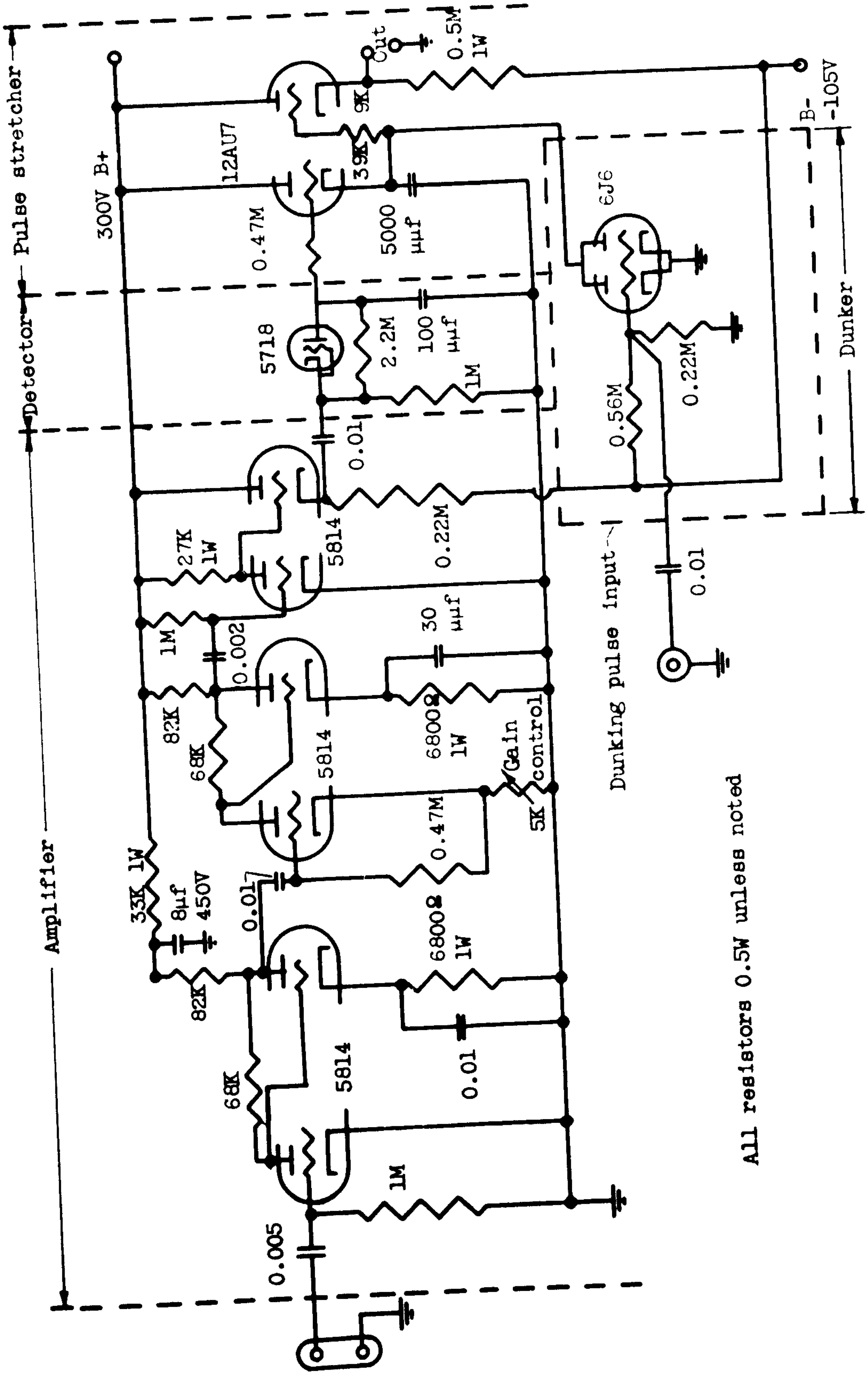


Figure 3. - Pulse power supply.

3255



All resistors 0.5W unless noted

Figure 4. - Pulse amplifier and stretcher.

3255

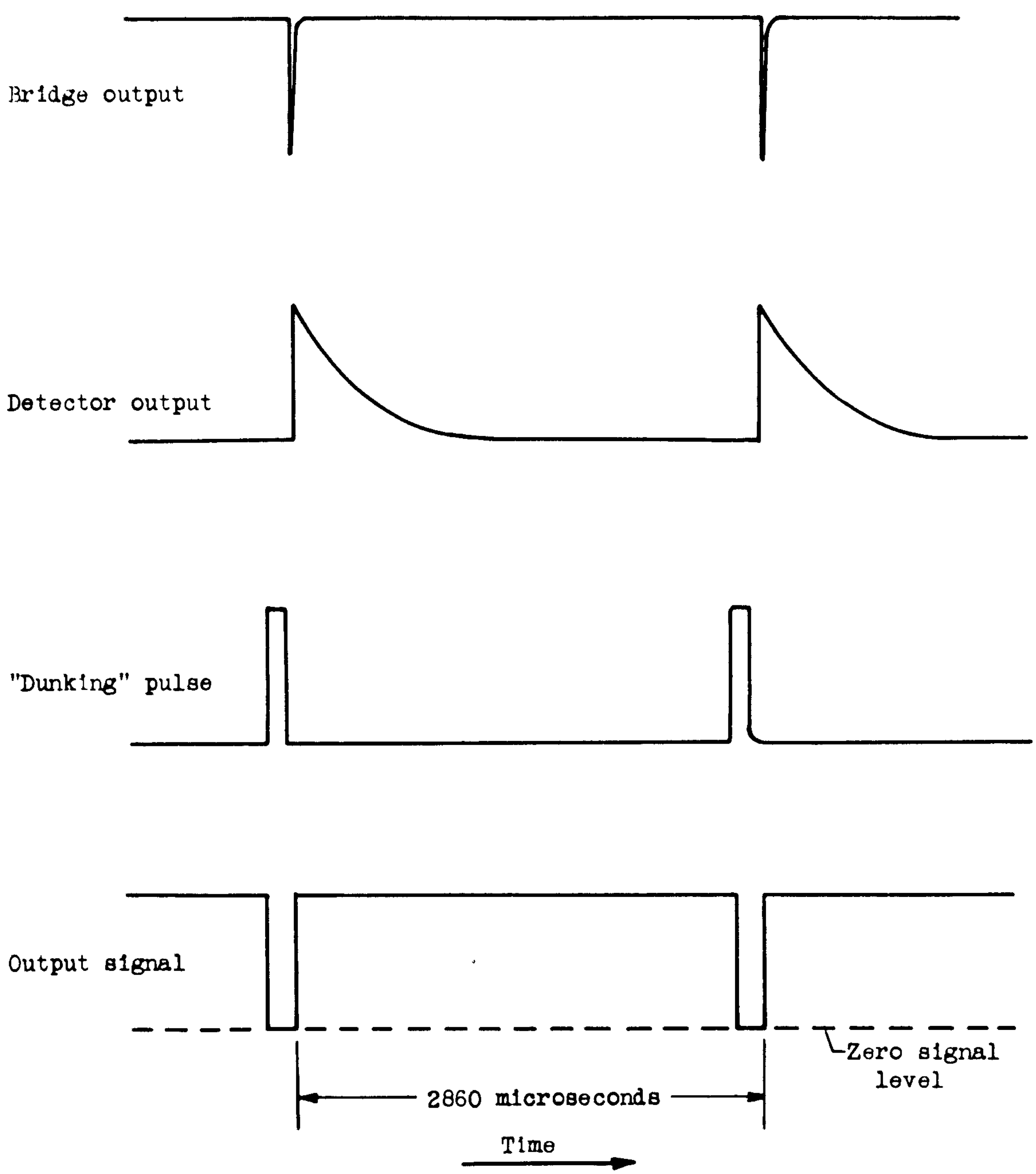


Figure 5. - Wave forms.

3255

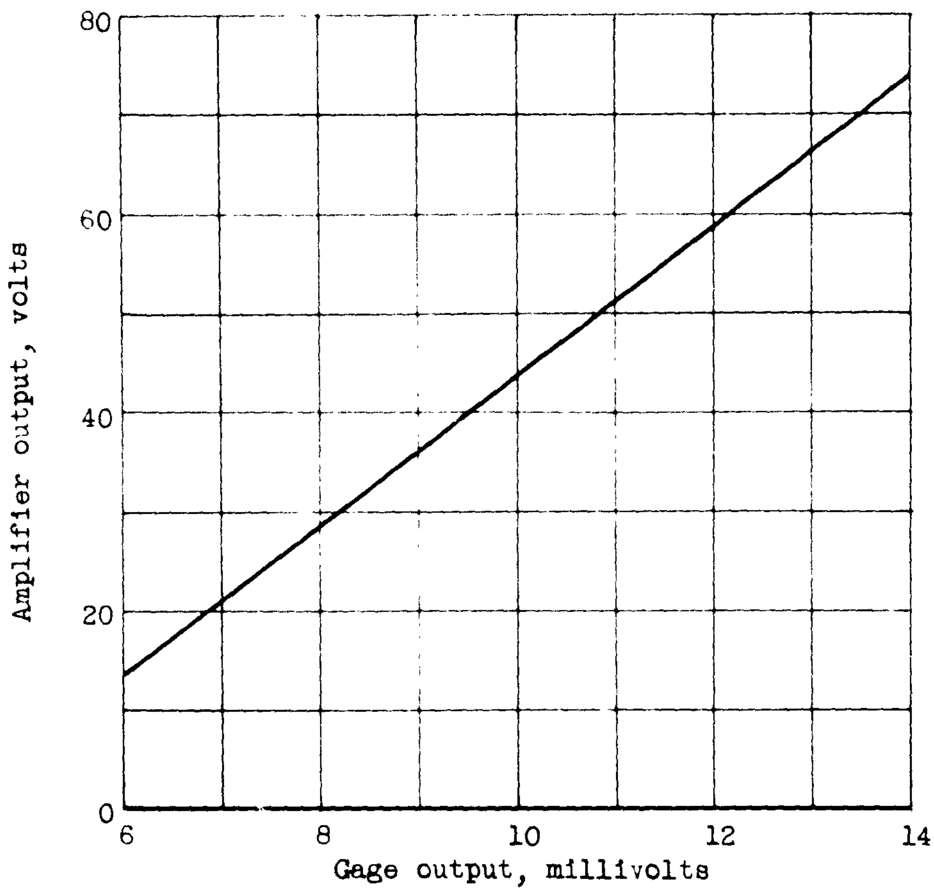
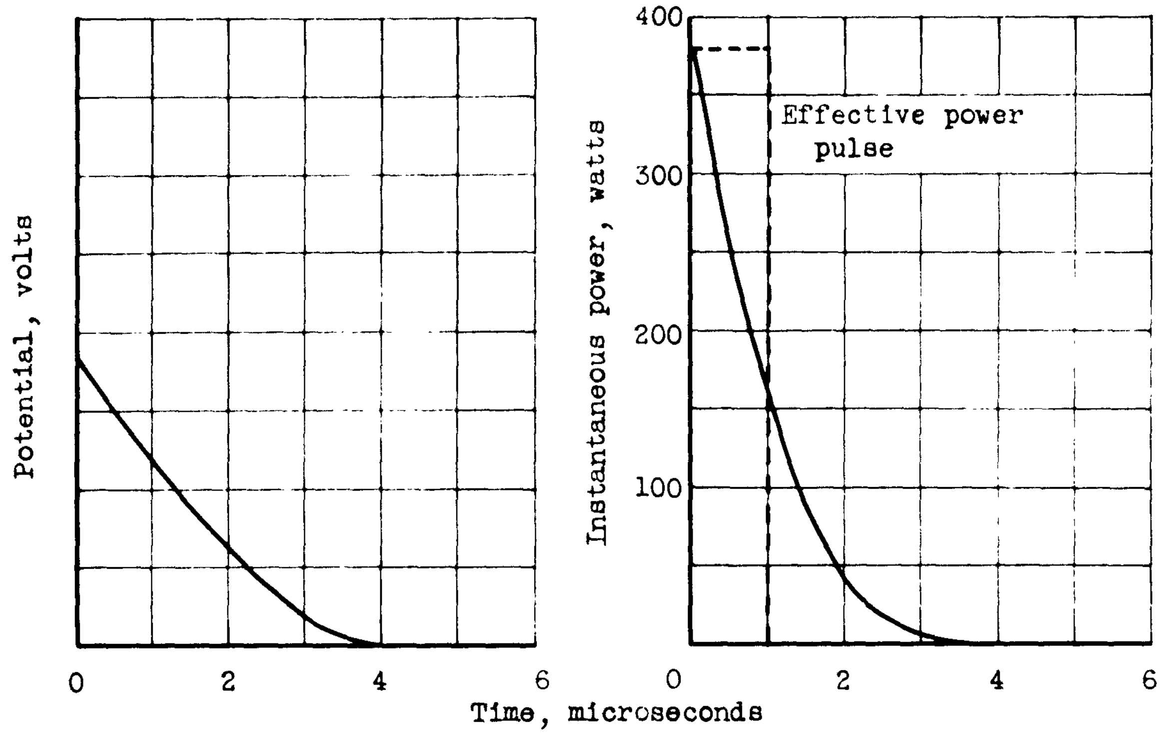


Figure 6. - Relation of amplifier output to input.

3255



(a) Potential applied to bridge terminals.

(b) Pulse power.

Figure 7. - Actual and equivalent effective pulses.

3255

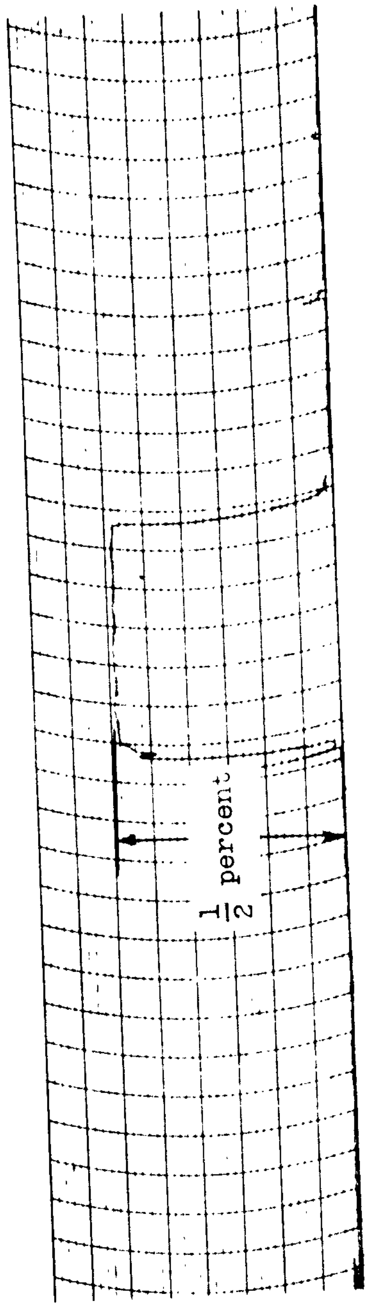


Figure 8. - Readability at small loads. Load, $\frac{1}{2}$ percent of full load.

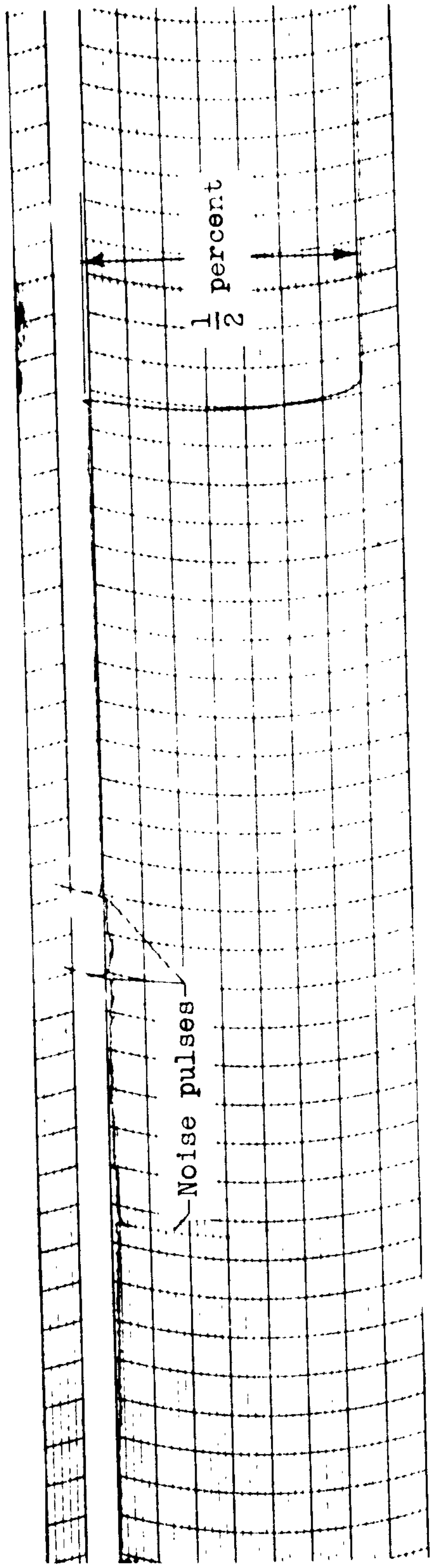


Figure 9. - Examples of noise pulse.

3255

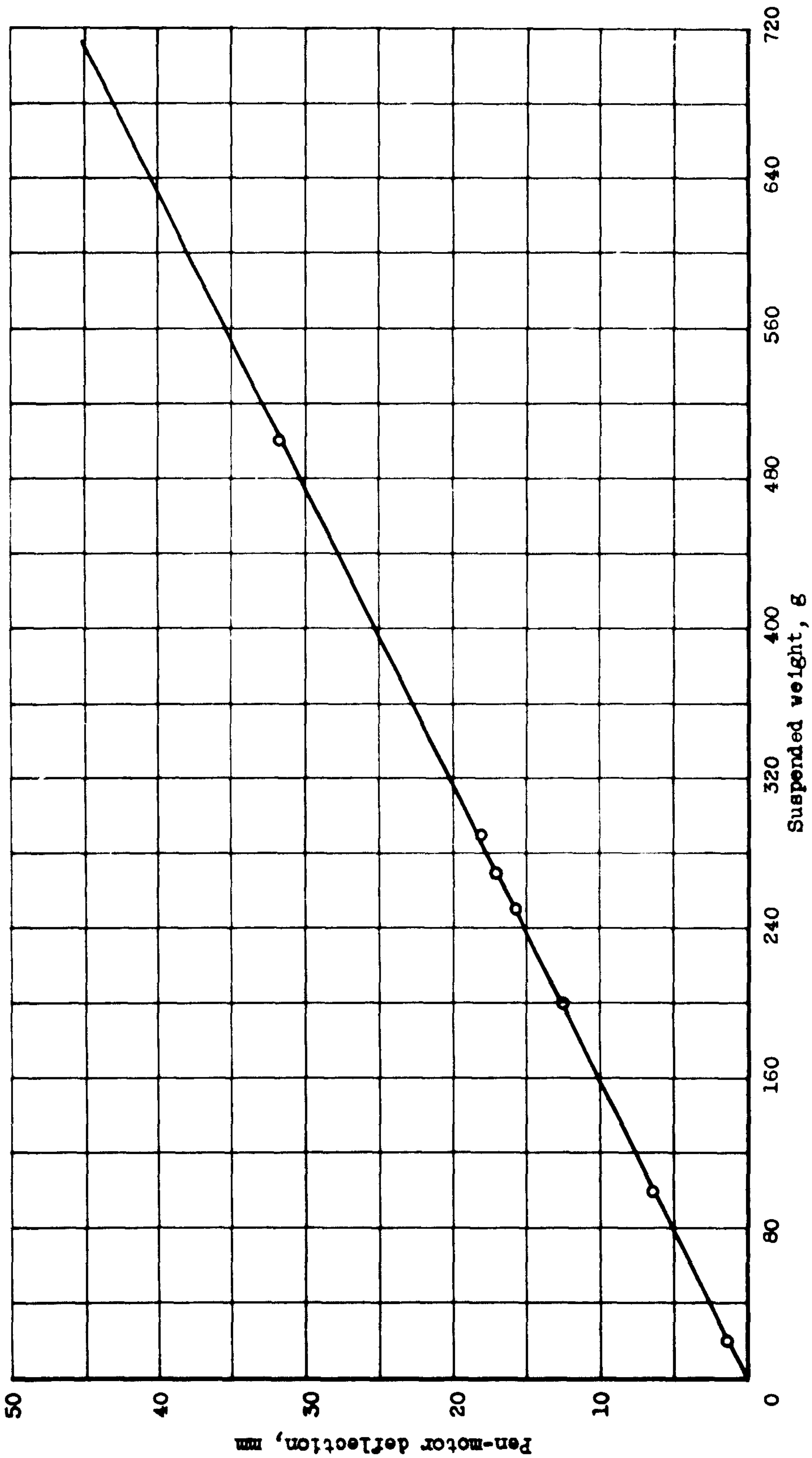


Figure 10. - Relation of input to output for complete system. Cantilever strain gage link with full load capacity of 90,800 grams.

NACA RM E54B08
National Advisory Committee for Aeronautics.
APPLICATION OF PULSE TECHNIQUES TO STRAIN GAGES. Newell D. Sanders and George H. Brodie. May 1954. 17p. diagrs. (NACA RM E54B08)

Pulse techniques have been applied to strain gages for increasing the output level and extending the usable range. Bonded and unbonded strain gages which normally operate with exciting potentials between 3.5 and 14 volts were operated satisfactorily with 200-volt pulses of 1-microsecond duration and a repetition rate of 350 per second. Outputs 15 times greater than normal outputs were measured. A pulse-generating circuit and a pulse-detecting circuit are described. An analysis of pulsed operation of strain gages is given.

Copies obtainable from NACA, Washington

1. Instruments, Laboratory (8.2)
I. Sanders, Newell Drake
II. Brodie, George H.
III. NACA RM E54B08

NACA RM E54B08
National Advisory Committee for Aeronautics.
APPLICATION OF PULSE TECHNIQUES TO STRAIN GAGES. Newell D. Sanders and George H. Brodie. May 1954. 17p. diagrs. (NACA RM E54B08)

Pulse techniques have been applied to strain gages for increasing the output level and extending the usable range. Bonded and unbonded strain gages which normally operate with exciting potentials between 3.5 and 14 volts were operated satisfactorily with 200-volt pulses of 1-microsecond duration and a repetition rate of 350 per second. Outputs 15 times greater than normal outputs were measured. A pulse-generating circuit and a pulse-detecting circuit are described. An analysis of pulsed operation of strain gages is given.

Copies obtainable from NACA, Washington

1. Instruments, Laboratory. (8.2)
I. Sanders, Newell Drake
II. Brodie, George H.
III. NACA RM E54B08

NACA RM E54B08
National Advisory Committee for Aeronautics.
APPLICATION OF PULSE TECHNIQUES TO STRAIN GAGES. Newell D. Sanders and George H. Brodie. May 1954. 17p. diagrs. (NACA RM E54B08)

Pulse techniques have been applied to strain gages for increasing the output level and extending the usable range. Bonded and unbonded strain gages which normally operate with exciting potentials between 3.5 and 14 volts were operated satisfactorily with 200-volt pulses of 1-microsecond duration and a repetition rate of 350 per second. Outputs 15 times greater than normal outputs were measured. A pulse-generating circuit and a pulse-detecting circuit are described. An analysis of pulsed operation of strain gages is given.

Copies obtainable from NACA, Washington

1. Instruments, Laboratory (8.2)
I. Sanders, Newell Drake
II. Brodie, George H.
III. NACA RM E54B08

NACA RM E54B08
National Advisory Committee for Aeronautics.
APPLICATION OF PULSE TECHNIQUES TO STRAIN GAGES. Newell D. Sanders and George H. Brodie. May 1954. 17p. diagrs. (NACA RM E54B08)

Pulse techniques have been applied to strain gages for increasing the output level and extending the usable range. Bonded and unbonded strain gages which normally operate with exciting potentials between 3.5 and 14 volts were operated satisfactorily with 200-volt pulses of 1-microsecond duration and a repetition rate of 350 per second. Outputs 15 times greater than normal outputs were measured. A pulse-generating circuit and a pulse-detecting circuit are described. An analysis of pulsed operation of strain gages is given.

Copies obtainable from NACA, Washington

1. Instruments, Laboratory (8.2)
I. Sanders, Newell Drake
II. Brodie, George H.
III. NACA RM E54B08